NASA Exploration Systems Technology & Systems Integration
Technical Interchange Meeting (ESTSI – TIM)

Advanced Life Support Systems

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Abstract/Summary

This presentation is planned to be a 10-15 minute “catalytic” focused presentation to be scheduled during one of the working sessions at the TIM. This presentation will focus on Advanced Life Support technologies key to future human Space Exploration as outlined in the Vision, and will include basic requirements, assessment of the state-of-the-art and gaps, and include specific technology metrics. The presentation will be technical in character, lean heavily on data in published ALS documents (such as the Baseline Values and Assumptions Document) but not provide specific technical details or build to information on any technology mentioned (thus the presentation will be benign from an export control and a new technology perspective). The topics presented will be focused on the following elements of Advanced Life Support: air revitalization, water recovery, waste management, thermal control, habitation systems, food systems and bioregenerative life support.

The following presentation is a rough preliminary cut. The content will likely change as content is discussed and coordinated with other attendees, including Carl Walz and Mark Jernigan.

Human Life Support Consumables & Wastes

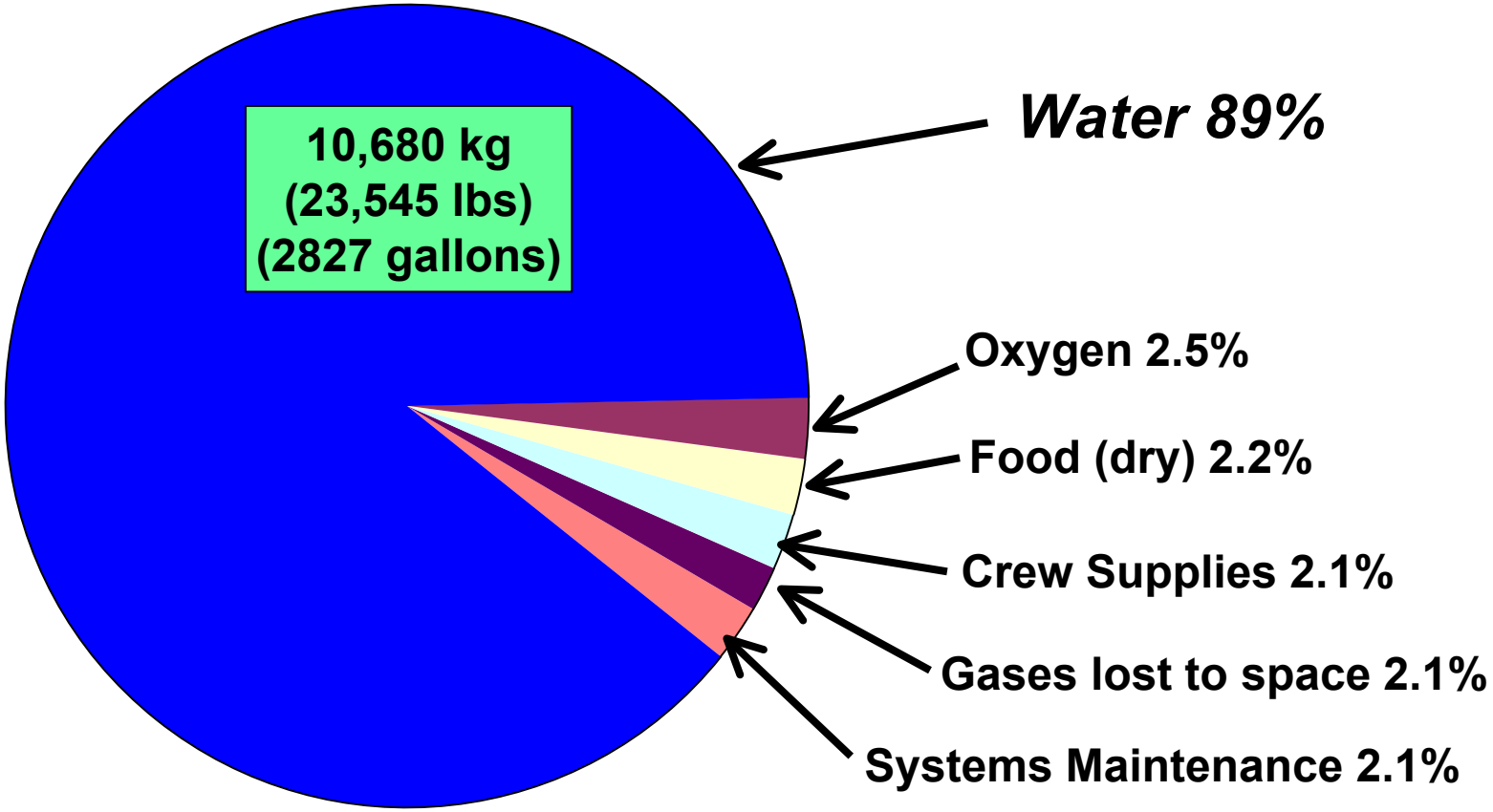
Consumables	Kilograms per person per day	
Gases		**0.8**
Oxygen	0.84	
Water		**23.4**
Drinking	1.62	
Water content of food	1.15	
Food preparation water	0.79	
Shower and hand wash	6.82	
Clothes wash	12.50	
Urine flush	0.50	
Solids		**0.6**
Food	0.62	
TOTAL		**24.8**

Wastes	Kilograms per person per day	
Gases		**1.0**
Carbon Dioxide	1.00	
Water		**23.7**
Urine	1.50	
Perspiration/respiration	2.28	
Fecal water	0.09	
Shower and hand wash	6.51	
Clothes wash	11.90	
Urine flush	0.50	
Humidity condensate	0.95	
Solids		**0.2**
Urine	0.06	
Feces	0.03	
Perspiration	0.02	
Shower & hand wash	0.01	
Clothes wash	0.08	
TOTAL		**24.9**

Human Life Support Technology Drivers

- Basic Human Life Support Requirements
- Crew Size
- Mission Duration
- ISRU and Planetary Protection
- Availability/Allocation of Spacecraft Resources
  - Volume
  - Mass
  - Heat Rejection
  - Power
  - Crew Time
- Cabin Pressure
- The “ilities”: Safety, Reliability, Maintainability, etc.
- Requirements for Contingency, Redundancy and Spares

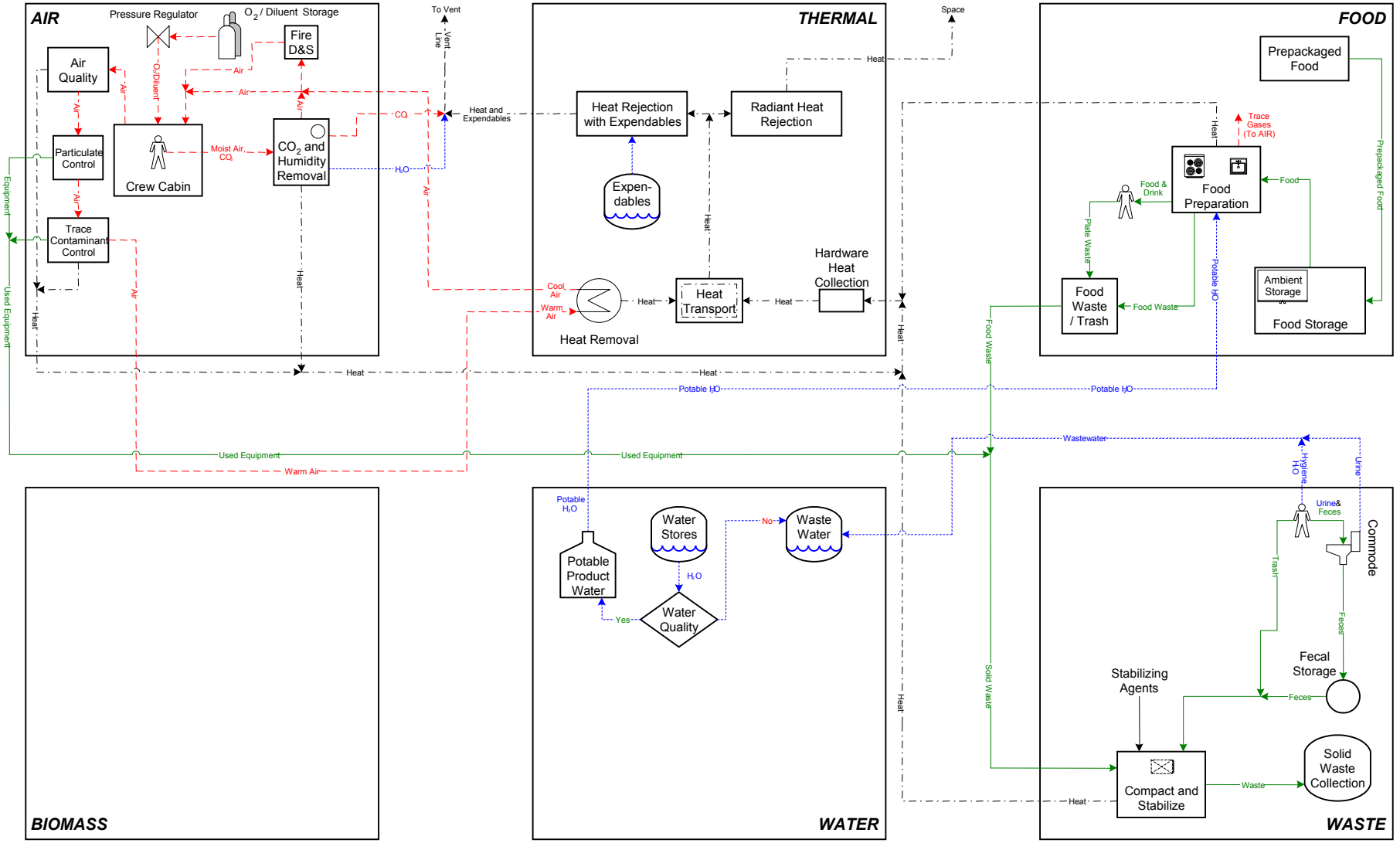
Open-Loop Life Support System
Resupply Mass - 12,000 kg/person-year
(26,500 lbs/person-year)



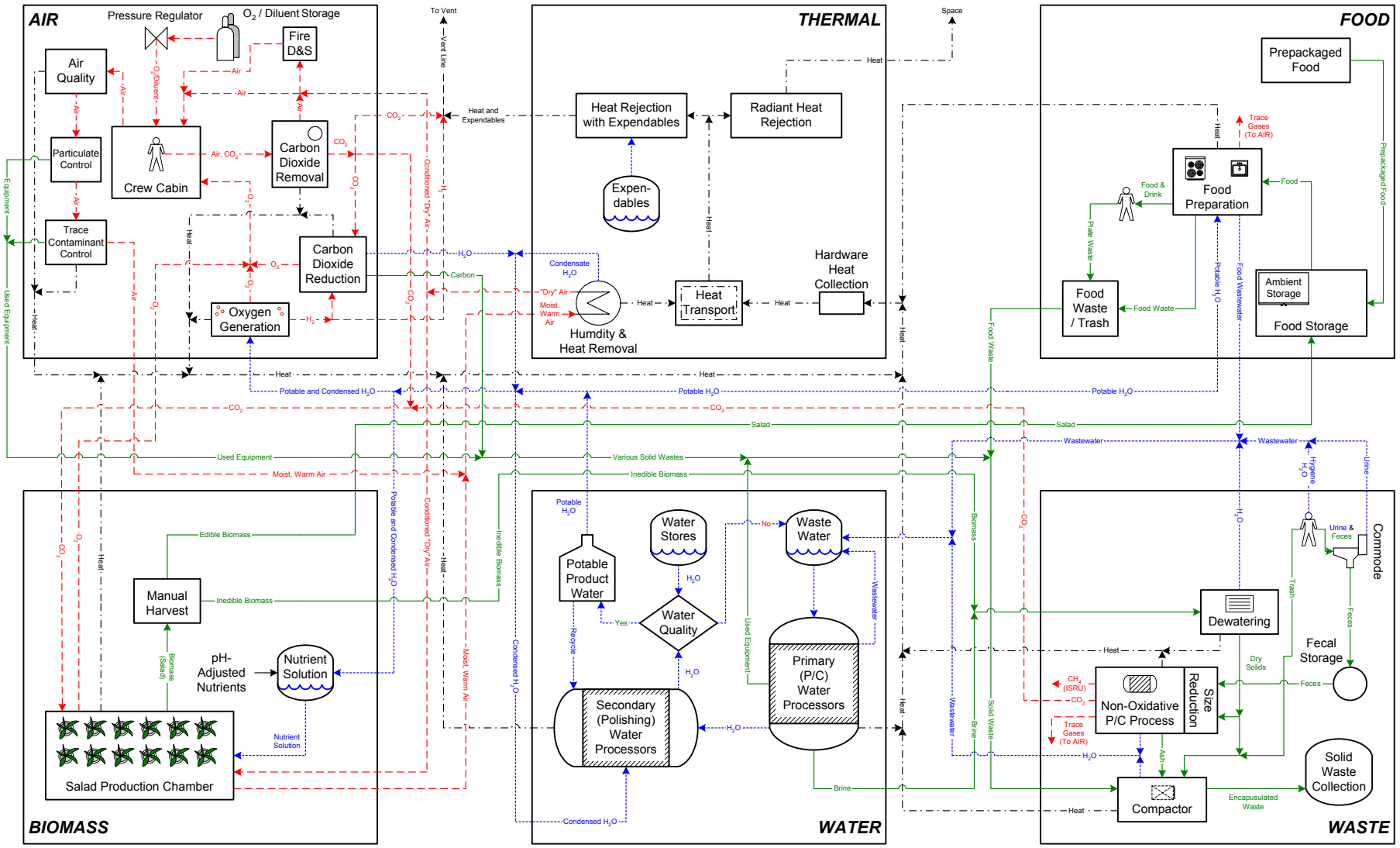
Parameters for Human Life Support Across Mission Scenarios

Mission / System	Lunar Transit Vehicle	Lunar Landing Vehicle	Pressurized Rover	Mars Landing Vehicle	Mars Transit Vehicle	Lunar Habitat	Mars Habitat
SPIRAL	1	2	5	5	4	3	5+
Duration (Human Tended)	8 – 10 days (Roundtrip)	3-14 days	1 – 7 days	30 days	12 – 24 months (Roundtrip)	2-3 months	18 months
Air Revitalization	Open	Open	Open	Open	Closed	Closed	Closed ISRU
Water Recovery	Collection and Storage	Collection and Storage	Collection and Storage	Collection and Storage	Closed	Closed	Closed ISRU
Waste Management	Stored	Stored	Stored	Volume Reduction Stabilization	Volume Reduction Stabilization De-watering	Volume Reduction Mineralization Stabilization Resource Recovery	Volume Reduction Mineralization Stabilization Resource Recovery
Food Systems	Conven-tional Stored	Conven-tional Stored	Extended Shelf Life	Extended Shelf Life	Extended Shelf Life with Fresh Food Augmentation	Conventional Stored with Fresh Food Augmentation	Extended Shelf Life with Food Production

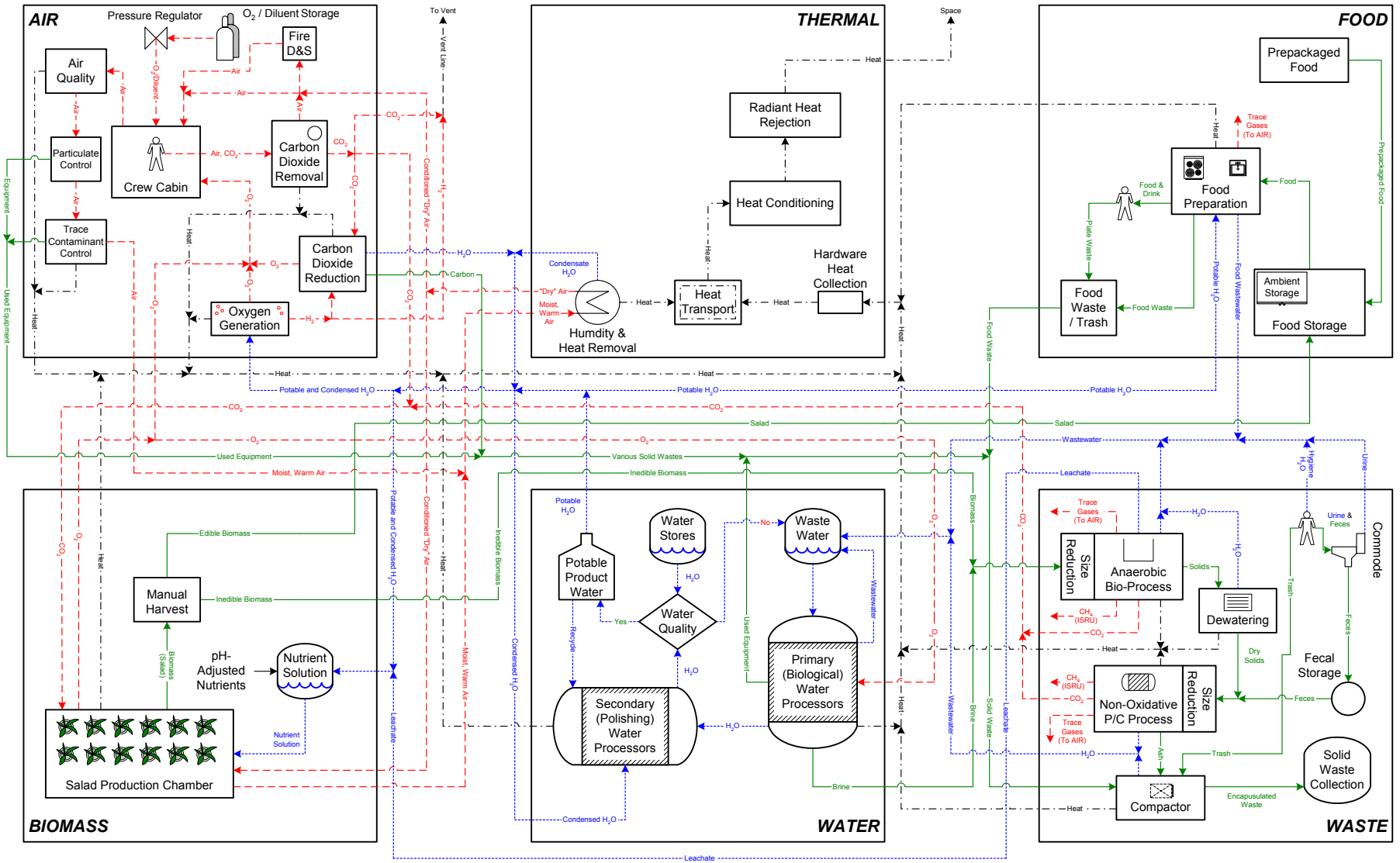
Life Support System Schematic for Short Duration Spacecraft



Life Support System Schematic for Long Duration Transit Vehicle



Life Support System Schematic for Long Duration Surface Habitats



Water Recovery and Supply

- Technologies for Water Recovery
  - Primary processing - organic and nitrogenous contaminant reduction
    - Distillation
    - Membrane separation
    - Biological oxidation
  - Secondary processing - inorganic contaminant reduction
    - Distillation
    - Reverse osmosis
  - Brine dewatering - water removal from highly concentrated brine
    - Distillation
    - Spray drying
  - Post-processing – polishing and disinfection to meet potability standards
    - Catalytic Oxidation
    - Photolysis
    - Ion exchange
    - Residual disinfection
  - Integration, modeling and analysis
    - Testing with human-generated wastewater to validate system performance
    - Low-gravity experiments and modeling for multiphase-based technologies.
    - Explicitly define criteria for “gravity independent” systems.
    - Develop scaling laws for normal to zero as well as *partial gravity* systems.

Water Recovery Systems Gap Analysis

- Gaps
  - No water processing hardware have been used on US spacecraft
  - Current plan for ISS:
    - Physical/chemical urine processing with downstream processing from consumable beds. Dependent on 90-day resupply
  - Currently developed filtration technologies are too power and consumable-intensive
  - Presence and characteristics of planetary water are unknown
- Needs
  - Regenerable water recovery system to avoid resupply dependence
  - Focused investment in biological water processing
    - Low mass, low power, low consumables
  - Novel brine dewatering techniques
  - Advancement of current technologies up to and beyond TRL 6

Required Capability	Now	Figure of Merit in FY2008	Long Term
Biological primary processor effluent TOC value	45mg/L	30mg/L	20 mg/L
PC primary processor equivalent system mass (ESM)	696	146	100
Secondary processor operating pressure	750psi	300psi	200psi
Brine dewatering system ESM	392	146	100
Post-processing consumable usage	30 kg/yr	15 kg/yr	5 kg/yr
Post-processing power usage	200W	100W	75W
Resin consumed to remove biocide	0.6g/kg of water processed	0g/kg of water processed	0g/kg of water processed

Water Recovery and Supply

Mission	Mission Characteristics	Closure Desired	Current Capabilities	Gaps
Spiral 1 Crew of 4-6 to Low Earth Orbit (2014)	• Launch environment • LEO environment • Lunar transit configuration • Earth entry, water or land recovery • No current ISS visit required • Duration: < 10 days	Open Loop	• Stored Water • Iodine/Silver Disinfection	• Improved Disinfection
Spiral 2 Crew of 4-6 to Lunar Surface for Extended Duration (2015-2020)	Above characteristics AND • Earth-moon cruise • Low lunar orbit operations • Lunar surface operations • Low lunar orbit operations • Moon-Earth cruise • Duration: 4-14 days	Open Loop	• Stored Water • Iodine/Silver Disinfection	• Improved Disinfection
Spiral 3 Crew to Lunar Surface for Long Duration Stay (2020-TBD)	Above characteristics AND • Lunar surface operations • Duration: 60-90 days	Complete Closure	• Distillation (~87.5% Recovery) • Multifiltration & Ion Exchange • Catalytic Oxidation • Iodine Disinfection	• Distillation with >90% recovery • Ambient temp oxidation • UV oxidation • Bioregenerative water processing
Spiral 4 Crew to Mars Vicinity (2030+)	• Earth-Mars cruise: 6-9 Mo. • Mars vicinity operations 1-3 months • Mars-Earth cruise: 9-12 Mo. • Duration: 16-24 months	Complete Closure	• Distillation (~87.5% Recovery) • Multifiltration & Ion Exchange • Catalytic Oxidation • Iodine Disinfection	• Distillation with >90% recovery • Ambient temp oxidation • UV oxidation • Bioregenerative water processing

Air Revitalization – Function, State of the Art & Gaps

- Gas Supply (oxygen, nitrogen)
  Functions:
    - Monitor and control partial pressures of atmospheric gases
    - Monitor and control total cabin pressure
    - Provide atmospheric gases
        - Gas storage systems
        - Recover and/or produce useable gases from waste streams
        - Separate and/or purify useable gases from *in situ* resource utilization systems
  - State of the Art:
    - Cryogenic storage (Shuttle) and Pressurized storage (ISS)
    - Oxygen candles
    - Water electrolysis (ISS-flight unit integrated in rack, to fly by 2006)
  - Gap Analysis:
    - Need for high pressure electrolysis to fill tanks and support EVA
    - Reductions in energy cost & improved reliability of oxygen generation
    - Light weight storage systems; low pressure liquid storage alternatives for improved safety
    - Regeneration of supply gases from spacecraft waste streams
- Carbon Dioxide & Atmospheric Water Systems
  Functions:
    - Remove carbon dioxide from cabin atmosphere
    - Control humidity in cabin atmosphere
    - Process carbon dioxide for recovery of oxygen
  - State of the Art:
    - Condensing heat exchange with centrifugal phase separation (Shuttle & ISS)
    - Granular LiOH (Shuttle-primary; ISS-backup)
    - Thermal/vacuum swing adsorption using zeolites with water save (ISS)
    - Vacuum swing adsorption using supported amines with no water save (Shuttle DTO)
  - Gap Analysis:
    - Regenerative technologies to reduce expendables, reduce power, mass & heat rejection
    - Recovery, concentration and reduction of carbon dioxide for production of oxygen (Closing the Air Loop); recovery of hydrogen from wastes
    - Fault-tolerant, efficient porous/membrane heat exchangers with integral phase separation

Air Revitalization – Function, State of the Art & Gaps

- 6.1.1.1.3 Atmospheric Contaminant Systems
  Functions:
    - Monitor & remove trace gas contaminants from cabin atmosphere
    - Monitor & remove particulate matter from cabin atmosphere, including microorganisms
  - State of the Art:
    - Activated carbon adsorption (Shuttle/ISS-expendable fixed beds in US Segment, regenerable beds in Russian Segment)
    - Thermal catalytic oxidation (ISS)
    - Ambient temperature catalytic oxidation of CO (Shuttle/ISS backup)
    - Debris filters (Shuttle)
    - HEPA filters (ISS)
  - Gap Analysis:
    - Reduction in consumables, energy, capacity and efficiency
    - Regeneration of filters and adsorption beds
    - Multi-functionality and integrated systems
    - Treatment of effluents & products of water and waste processors and products produced from *in situ* resource utilization systems
- 6.1.1.1.4 Ventilation
  - Function: Provide atmospheric mixing
  - State of the Art:
    - Axial fans (Shuttle/ISS)
    - Portable ventilation fans (ISS)
    - Fixed ducts (ISS)
  - Gap Analysis:
    - Need to reduce noise, pressure drops, power and volume
    - Improvements through systems analysis

Atmosphere Revitalization

Mission	Mission Characteristics	Closure Desired	Current Capabilities	Gaps
Spiral 1 Crew of 4-6 to Low Earth Orbit (2014)	• Launch environment • LEO environment • Lunar transit configuration • Earth entry, water or land recovery • No current ISS visit required • Duration: < 10 days	Open Loop	• LiOH Canisters • Amine based systems	• Improved LiOH packaging • Improved amines for CO_2 and H_2O
Spiral 2 Crew of 4-6 to Lunar Surface for Extended Duration (2015-2020)	Above characteristics AND • Earth-moon cruise • Low lunar orbit operations • Lunar surface operations • Low lunar orbit operations • Moon-Earth cruise • Duration: 4-14 days	Open Loop	• LiOH Canisters • Amine based systems	• Improved LiOH packaging • Improved amines for CO_2 and H_2O Control • Regenerable Trace Contaminant
Spiral 3 Crew to Lunar Surface for Long Duration Stay (2020-TBD)	Above characteristics AND • Lunar surface operations • Duration: 60-90 days	Partially Closed	• LiOH Canisters • Amine based Systems • Molecular sieves • Oxygen generation	• Regenerable Amine Sys. • Efficient molecular bed systems • CO_2 reduction • Regenerable Trace Contaminant • High pressure O2 generation
Spiral 4 Crew to Mars Vicinity (2030+)	• Earth-Mars cruise: 6-9 Mo. • Mars vicinity operations 1-3 months • Mars-Earth cruise: 9-12 Mo. • Duration: 16-24 months	Complete Closure	• LiOH Canisters • Amine based Systems • Molecular sieves • Oxygen generation	• Efficient molecular sieve systems • More options for CO_2 reduction systems • Regenerable Trace Contaminant

Spacecraft Cabin Thermal Management Systems

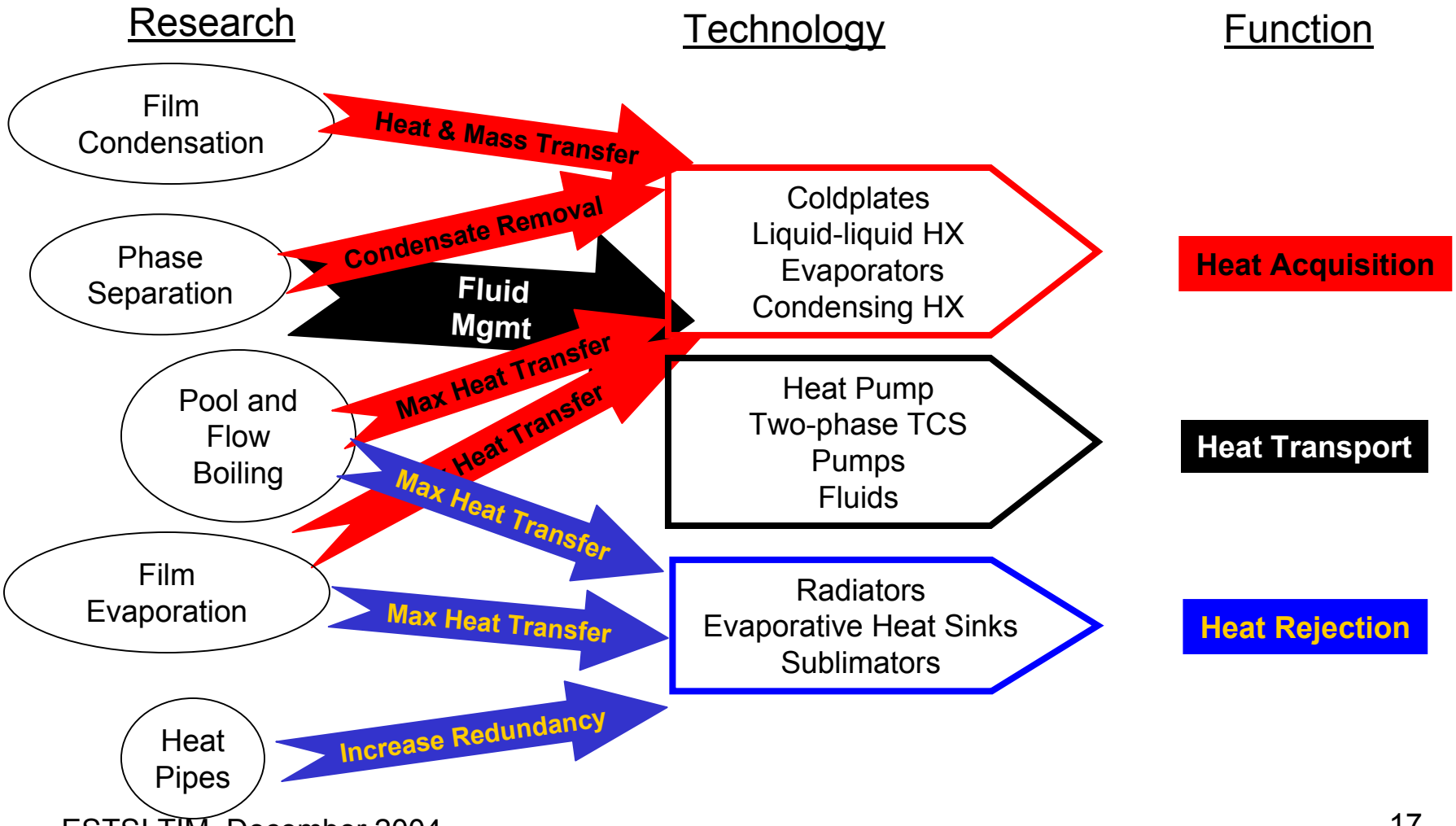
Current State of the Art

Function	State of the Art
Heat Acquisition and Humidity Control	• **Metal coldplates (Shuttle, ISS)** • **Liquid to liquid heat exchangers (Shuttle, ISS)** • **Condensing heat exchanger with "slurper" bar and rotary separator for humidity control (Shuttle, ISS)**
Heat Transport	• **Single phase pumped fluid loops (Shuttle, ISS)** • **Internal water loop (Shuttle, ISS)** • **External refrigerant loop (Freon 21 - Shuttle, ammonia – ISS)**
Heat Rejection	• **Aluminum radiators (Shuttle, ISS)** • **Porous plate sublimators (EMU, Apollo LM)** • **Flash Evaporator System (Shuttle)**

Existing technology does not use latent heat of vaporization, leading to single phase, large heat rejection systems.

Spacecraft Cabin Thermal Management Systems

Technologies for each function - The following flow diagram shows the links between research, hardware development, and Thermal Control Functions



Spacecraft Cabin Thermal Management Systems

Mission	Mission Characteristics	Closure Desired	Current Capabilities	Gaps
Spiral 1 Crew of 4-6 to Low Earth Orbit (2014)	• Launch environment • LEO environment • Lunar transit configuration • Earth entry, water or land recovery • No current ISS visit required • Duration: < 10 days	Some Expendables	• Metal radiators • Flash evaporator • Ammonia boiler	• Lightweight radiators • Multi-fluid evaporator • Contamination insensitive sublimator • Improved heat exchangers
Spiral 2 Crew of 4-6 to Lunar Surface for Extended Duration (2015-2020)	Above characteristics AND • Earth-moon cruise • Low lunar orbit operations • Lunar surface operations • Low lunar orbit operations • Moon-Earth cruise • Duration: 4-14 days	Some Expendables	• Metal Radiators • Flash evaporator • Ammonia boiler	• Lightweight radiators • Multi-fluid evaporator • Heat pump • Contamination insensitive sublimator • Improved heat exchangers
Spiral 3 Crew to Lunar Surface for Long Duration Stay (2020-TBD)	Above characteristics AND • Lunar surface operations • Duration: 60-90 days	No Expendables	• Metal radiators	• Lightweight radiators • Heat pump • Radiator shades • Improved heat exchangers, Cooling Jackets & Cold Plates
Spiral 4 Crew to Mars Vicinity (2030+)	• Earth-Mars cruise: 6-9 Mo. • Mars vicinity operations 1-3 months • Mars-Earth cruise: 9-12 Mo. • Duration: 16-24 months	No Expendables	• Metal radiators	• Lightweight radiators • Body mounted radiators • Improved heat exchangers, Cooling Jackets & Cold Plates

Solid Waste Management - Functions

- Volume Reduction **– Recovers habitable volume and reduces ESM. Achieved by compaction, particle size reduction, and/or mineralization.**
- Drying/Water Recovery **– Water recovery increases system closure, reduces ESM and provides stabilization/safening.**
- Clothes Washing/Recovery **– Enables reuse rather than disposal of clothing and decreases ESM for extended missions.**
- Mineralization **- Transformation of waste to its elemental components – provides significantly increased stabilization/safening and volume reduction and can increase system closure via resource recovery. Reduces ESM.**
- Containment **– Controls risk of crew/planetary contact with wastes and by-products. Achieved by containers, procedures, or isolation. Satisfies planetary protection protocols.**
- Disposal **– Decreases internal mass (propulsion costs) and volume by transfer to interplanetary space or planetary surface. Container ejection must avoid negative impacts with the spacecraft in space or harmful effect on a planetary surface.**
- Particle Size Reduction **– Numerous waste processing technologies require size reduction of particles to facilitate efficient operation. Feedstock size requirements are technology specific.**
- Resource Recovery **– Key requirement for life support systems approaching self-sufficiency. Resources recovered include water, clothes, CO_2, other materials and plant nutrients. Technology attributes depend on the resource to be recovered. Reduces ESM.**

Solid Waste Management Technologies

Technologies for Each Function

- Volume Reduction **– Plastic heat melt compactor (ratio of 10 to 1 reduction), particle size reduction, and/or mineralization technologies.**
- Drying/Water Recovery **– Lyophilization (freeze-drying), heated air-drying, and vacuum drying. Water also generated via waste physicochemical and biological oxidation.**
- Clothes Washing **– Micro/hypo gravity washer that minimizes water and soap usage.**
- Mineralization **– Incineration, hydrothermal oxidation, pyrolysis, composting (biological)**
- Containment **– Long duration (>200 years) containment systems (containers, procedures, or isolation).**
- Disposal **– Proper systems to facilitate disposal in interplanetary space and on planetary surfaces.**
- Particle Size Reduction **– Grinding, cutting and shredding technologies that function in micro/hypo-gravity.**
- Resource Recovery **– Drying systems, pyrolytic systems, oxidation systems, clothes washing systems.**

Solid Waste Management

Potential ESM Savings via Enhanced Waste Management Operations

Current ISS vs. ALS Technologies for a Mars Exploration Mission (600 days)

Item	ISS ESM	ALS ESM	Delta	Comment
Waste (clothing, feces, food packaging, scraps, etc.) Safener - e.g. container vs. mineralizer	**3,933**	**1,000**	2,933	**assume containers for ISS - processor for ALS**
Waste Disposal on Mars surface	**5,899**	**1,000**	4,899	**savings on return propulsion**
Water in feces and waste	**2,000**	**500**	1,500	**water saving vs. cost**
Clothing	**6,780**	**1,200**	5,579	**clothes washer**
Compaction	**3,000**	**1,000**	2,000	**assume crewed vol=200 kg/m^3, ISS is 1/2 compact by handed**
Total	17,679	3,700	13,978	

Solid Waste Treatment Management

Mission	Mission Characteristics	Closure Desired	Current Capabilities	Gaps
Spiral 1 Crew of 4-6 to Low Earth Orbit (2014)	• Launch environment • LEO environment • Lunar transit configuration • Earth entry, water or land recovery • No current ISS visit required • Duration: < 10 days	Open Loop	• Storage • Hand compaction	• Improved compaction
Spiral 2 Crew of 4-6 to Lunar Surface for Extended Duration (2015-2020)	Above characteristics AND • Earth-moon cruise • Low lunar orbit operations • Lunar surface operations • Low lunar orbit operations • Moon-Earth cruise • Duration: 4-14 days	Open Loop	• Storage • Hand compaction	• Improved compaction • Planetary protection requirements
Spiral 3 Crew to Lunar Surface for Long Duration Stay (2020-TBD)	Above characteristics AND • Lunar surface operations • Duration: 60-90 days	Partially Closed	• Storage • Hand compaction	• Improved compaction • Stabilization technologies
Spiral 4 Crew to Mars Vicinity (2030+)	• Earth-Mars cruise: 6-9 Mo. • Mars vicinity operations 1-3 months • Mars-Earth cruise: 9-12 Mo. • Duration: 16-24 months	Partially Closed	• Storage • Hand compaction	• Improved compaction • Resource recovery technologies • Stabilization technologies

Solid Waste Management

Technical Challenges:

- Universal Challenges – Micro/hypo-gravity performance, automation, minimizing mass, power and volume, waste pretreatment requirements
- Compaction - Assuring complete encapsulation, confirmation of biological safening, maximizing volume reduction
- Water Recovery Technologies – Maximizing water recovery, condenser performance, control of volatile contaminant release
- Clothes Washing – Minimization of water and detergent use
- Oxidation/Pyrolysis Technologies – Maximizing conversion, contaminant control, pressure and temperature control, corrosion resistance
- Containment/Disposal - Corrosion resistance, material strength, longevity, ejection reliability
- Resource Recovery – Product quality, maximization of recovery, reliability

Gaps to be Filled:

- Effective mechanical compaction to replace manual compaction
- Ability to recover water (currently no ability for water recovery from waste)
- Ability to reuse clothing
- Particle size reduction to 100 to 1000 micron range
- Proper means for interplanetary and lunar/planetary disposal
- Long duration containment
- Disinfecting and/or stabilizing (safening) waste

Bioregenerative Life Support

- Plants can provide fresh foods to supplement the crew diet on Lunar, Mars transit, and Mars surface missions. These supplements could be provided from an area as small as 1-2 m^2.

- Plants remove CO_2, generate O_2, and produce clean water that can be condensed and recycled to the crew. This atmospheric regeneration and water purification can be used to unload existing ECLSS equipment and provide system redundancy and mission autonomy.
  - 5 m^2 of plants could recycle wastewater for 1 person
  - 25 m^2 of plants could provide the O_2 and CO_2 removal for 1 person
  - 50 m^2 of plants could meet food needs for 1 person

- Plants and their growing system may provide a positive psychological influence to the crew (e.g., aromas, higher humidity, bright light). Although data are scant, this area requires further testing to assess the full impact of plants to conduct more accurate trade studies.

Bioregenerative Life Support

- **Description:**
  - Plants for dietary supplements: Fresh vegetables and fruits only keep for a few days to ~1 month. Small-scale (1-5 m^2) plant growing systems can be used to provide fresh foods on a continuous basis.
  - Plants as atmospheric regenerators: Under moderate-high light intensity, plants can generate ~30 g O_2 m^{-2} day^{-1}, and remove ~40 g CO_2 m^{-2} day^{-1}.
  - Plants as water processors: At typical humidities (e.g., 50-70%), plants transpire ~5 kg m^{-2} day^{-1}. Thus plant growing systems can serve as a final processing step for removing minerals and evaporating water.

- **Requirements**:
  - Establish requirement for fresh foods in crew diet. Establish requirement for antioxidants in diet of humans living in space environments.
  - Verify scalability of plant biomass production and gas exchange under different environments (e.g., light intensity, light spectrum, pressure, pCO_2, and radiation).
  - Demonstrate wastewater processing / integration with plant systems.

Bioregenerative Systems Gap Analysis

- **Current State of the Art**:
  - Plant outputs (food, O_2, and clean water) demonstrated for small-scales (~1 m^2) and single production cycles.
  - Conversion of electrical power to light and the subsequent generation of food, O_2, and CO_2 removal from light is relatively inefficient.
  - Physiological effects of fresh foods with antioxidants in humans living in high radiation, space environments is untested.
  - Psychological benefit of plants in isolated space environments is untested.
- **Needed State of the Art**:
  - Sustained performance of crops in medium (5-10 m^2) and large (10-100 m^2) systems.
  - 2 X improvement in conversion of electrical power to light, and 2 X improvement in conversion of light to biomass beyond current capability.
  - Dietary requirements for fresh foods and bio-available antioxidants.
- **What's Needed to Fill the Gap**:
  - Sustained production tests (500 and 1000-day) on small, medium and large scale with candidate crops.
  - Improved efficiencies of LED systems and alternate lighting technologies.
  - Design and testing of solar light capture / delivery systems.
  - Establish dietary and physiological benefits fresh plants foods.
  - Testing of plant performance for space environments, e.g., anticipated light intensity, light spectrum, pressure, pCO_2, and radiation for a given mission.
  - Design and test attachable plant modules with associated mechanization and automation for surface missions.

Food Management System

- Food Management System Tasks and Functions
  - Provide Stored Food System with a 3 – 5 year shelf life at ambient temperatures
    - Food Packaging
    - Food Preservation
    - Stored Food Stowage
  - Processed Food System Development
    - Crop and Stored Commodities Stowage
    - Process Crops and Stored Commodities
    - Processed Ingredient Stowage
  - Menu Development – food preparation in the galley using stored food system and processed foods
    - Food Preparation
    - Meets Nutritional Needs of Crew
    - Food Stowage
- Why necessary
  - The development of an advanced food system will enable support of humans beyond Low Earth Orbit (LEO).
  - Food must be safe, nutritious and acceptable to maintain crew health and well being throughout the entire mission
    - Food has a psychosocial element in addition to the nutrition
    - Crew performance and well-being dependent on a high quality food system
  - Food processing will provide the crew with a variety of fresh and nutritious foods

Stored Food System

3 – 5 year shelf life
- **Safe**
- **Nutritious**
- **Acceptable**
- **Minimize mass**

Justification/Rationale

- **Stored food system needed for transit mission and early lunar/planetary missions**
- **Stored food system will supplement planetary processed food system**
- **Improved barrier packaging will provide required shelf life**
- **Emerging preservation technologies will provide improved nutrition and acceptability**

Food packaging materials
- Low mass
- High barrier
- Easily processed as waste

Competing Technologies:
- None

Complementary Technologies:
- Current packaging materials used in retorted products

GAPS:
- **High barrier, non-metallized packaging materials**
- **Biodegradable and reusable packaging materials**

Preservation technologies
- Safe
- Nutritious
- Acceptable

Competing Technologies:
- None

Complementary Technologies:
- Retort processing

GAPS:
- **Emerging thermal and non-thermal technologies**
- **Product development of ~175 items**
- **Confirm shelf life including effect of radiation**

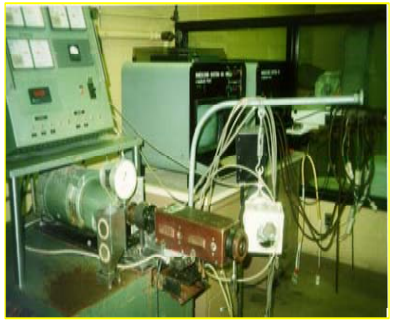
Food stowage
- Environmental conditions to maximize shelf life
- Inventory control to easily locate food items

Competing Technologies:
- None

Complementary Technologies:
- Shelf life testing of current items will provide storage requirements for retort items

GAPS:
- **Inventory management**
- **Storage conditions for non-retorted items**

Processed Food System



Processed ingredients from
- **Bulk stored ingredients**
- **Harvested crops**

Justification/Rationale
- **Processed food system will augment stored food system by increasing variety and acceptability and improving nutrition**
- **Food processing will provide food system closure and increase self sufficiency**
- **Food processing will decrease amount of stored food necessary for a mission**

Determine crop list
- Functionality needs for each crop or bulk ingredient
- Storage conditions for required shelf life of bulk ingredients and crops

Competing Technologies:
- **None**

Complementary Technologies:
- **None**

GAPS:
- **Determine products to produce from crops**
- **Determine crop "gold standard" for each crop**
- **Storage conditions for bulk ingredients and harvested crops**

Design and fabricate
- Miniaturized processing equipment
- Multifunctional processing equipment

Competing Technologies:
- None

Complementary Technologies:
- Prototype development: of fruit and vegetable processor and tofu processor

GAPS:
- **Development of ~30 pieces of equipment to TRL 6**
- **Determine effects of reduced G and atmospheric pressure on processing**

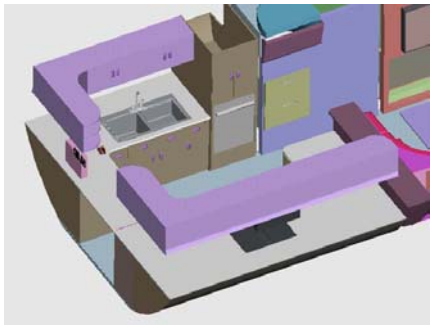
Processing procedures to provide food ingredients
- Safe
- Nutritious
- Acceptable

Competing Technologies:
- **None**

Complementary Technologies:
- **None**

GAPS:
- **Processing procedures (HACCP) using prototype equipment**
- **Clean-up procedures for each process (HACCP)**

Meal Preparation



Provide all meals for entire crew
- **Acceptable**
- **Nutritious**
- **Safe**
- **Psychosocial requirements**

Justification/Rationale
- **Menus that are nutritious and meets psychosocial requirements are necessary for long duration missions**
- **Food preparation procedures must be easy to understand and take minimal crew time**
- **Inventory management of food ingredients and prepared menu items must be complete and easily understood**

Galley
- Equipment fabrication
- Design and volume needs

Competing Technologies:
- **None**

Complementary Technologies:
- **None**

GAPS:
- **Equipment design and fabrication for ~30 pieces of galley equipment**
- **Galley design**

Menu development using
- Recipes using processed or bulk ingredients
- Fresh fruits and vegetables
- Prepackaged food items

Competing Technologies:
- None

Complementary Technologies:
- Initial development of recipes using bulk ingredients and fresh vegetables and fruits

GAPS:
- **Determine psychosocial requirements for a long duration space mission**
- **Nutritional content and acceptability of ~ 175 recipes**

Logistics
- Inventory management
- Food preparation
- Clean-up procedures

Competing Technologies:
- **None**

Complementary Technologies:
- **None**

GAPS:
- **Inventory management**
- **Food preparation procedures including effects of partial gravity and atmosphere**
- **Clean-up procedures**
- **Ingredient stowage**

Food Management System

- What is the current state of the art?
  - NASA
  - The current ISS food system is not adequate for mission longer than one year. The Food Management System approach includes a stored food system with increased shelf life, variety and acceptability, and processing systems that process raw food commodities into edible ingredients.
    - Food preservation
      - On Shuttle and ISS, the food system has a shelf life of 12 months for the freeze dried and natural form foods.
      - Thermostabilized and irradiated foods have a shelf life of 3 years
    - Food packaging
      - MRE pouch used for thermostabilized and irradiated foods has a high barrier to water and oxygen due to the aluminum layer (foil) However, it is dense and hard to process by solid waste processing team
      - Poly material used for freeze dried foods and natural form foods has poor barrier materials and is overwrapped with a foil pouch for ISS
- Food industry
  - The food industry does not require a 3 – 5 year shelf life
  - The focus of the food industry on barrier properties is less on barrier needs and more on packaging material clarity.
  - Miniaturized and multifunctional food processing equipment is not readily available

Food Management System

- With the exception of the military, no one else requires a shelf life of 5 years on a shelf stable, stored food system
- Only NASA is concerned with total mass of food system
  - For a crew of 5, 90 day mission, and use of only stored food system, the mass of the total amount of food and packaging is ~824kg (Spiral 3)
  - For a crew of 7, 1000 day mission, and use of only stored food system, the mass of the total amount of food and packaging is ~12,810kg (Spiral 5)
- Reduced gravity and reduced atmospheric pressure are unique to NASA and will affect food processing and preparation procedures
- NASA requires multifunctional food processing equipment that also minimizes while minimizing the use of resources for long-duration missions such as water usage, mass, crewtime, and volume
- More reliable capabilities are necessary to meet long-term exploration goals

Food Management System

- Deliverables with spiral applicability
  - Stored Food System
    - Develop high barrier food packaging without the use of a foil layer – Spiral 1 – 5, 2012
    - Develop food preservation technology to TRL6 – Spiral 1-5, 2012
    - Develop 150 food items with 5 year shelf life – Spiral 4-5, 2014
    - Develop 100 food items with 5 year shelf life – Spiral 5, 2016
    - Develop stored food stowage – Spiral 4-5, 2012
  - Food Crop Integration
    - Determine handling procedures of freshly grown vegetables – Spiral 1-5, 2006
    - Develop 15 pieces of food processing equipment to TRL 6 – Spiral 3, 5, 2018
    - Develop 15 pieces of food processing equipment to TRL 6 – Spiral 5, 2023
    - Develop 10 pieces of food processing equipment to TRL 6 – Spiral 5, 2028
    - Develop processed ingredient stowage – Spiral 3, 5, 2020
  - Menu Development
    - Determine psychosocial requirements of food system – Spiral 4, 2013
    - Modify COTS food preparation equipment to TRL 6 – Spiral 3, 5, 2016
    - Develop food preparation equipment to TRL 6 – Spiral 3, 5, 2015
    - Develop food preparation procedures – Spiral 3, 5, 2017
    - Develop recipes (~250) for surface mission – Spiral 3, 5, 2013
    - Develop food stowage requirements for prepared foods – Spiral 3, 5, 2019